The Use of Compensatory and Non-compensatory Multi-Criteria Analysis for Small-scale Forestry

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Small-scale farm forestry has the potential to offer many benefits both to landholders and the wider community. As with all changes in land-use practices, there are associated benefits and costs and these are not uniformly distributed. They have varying impacts on the different values, aspirations, goals and objectives that exist within the community. Furthermore, the community does not consider these values, aspirations, goals and objectives of equal importance. The degree of concern can vary from minor to high and overriding all other considerations. When evaluating farm forestry options it is necessary to address all of these concerns. This paper examines the combined use compensatory and non-compensatory multi-criteria analyses to evaluate forestry options, in a case study for the Darling Downs region of Queensland, Australia. These aggregation techniques are found to be highly complementary and together provide a comprehensive analysis. The compensatory technique provides a sound measure of overall performance of a forestry system, whereas the non-compensatory technique alerts decision-makers to presence of particularly poor performance with respect to individual criteria. The compensatory technique used is simple and understandable even for those with non-mathematical backgrounds. This analysis can identify and aid communication of the relative benefits and costs, and trade-offs, between economic, environmental and social considerations.

Keywords: Multi-Objective Decision Support Systems, farm forestry options, trade-offs, community participation

INTRODUCTION

Small-scale farm forestry could form an integral part of the rural landscape in many areas of Australia, providing economic, environmental and social benefits. Farm forestry may help to attain environmental quality objectives, such as reduction of demand to clear remnant vegetation, soil retention, improved water quality, carbon sequestration and salinity mitigation. From an economic perspective, forestry may diversify the products of a farming community and reduce risk associated with reliance on a single crop, provide a long-term and continuing product and revenue stream, or provide a nest-egg to be harvested at retirement. The extent to which

various farm forestry practices fulfil the objectives of economic enhancement, ecological enhancement and social and community enhancement needs to be assessed before appropriate systems can be recommended. In addition, a proposed change in practice should not seriously disadvantage any group in the local community or undermine the objectives of these groups.

Multi-criteria analysis is a decision-support process that aids decision-makers by providing a framework to gather and display the required data in a clear and transparent manner (Froger and Munda 1998). A multi-criteria analysis includes a finite number of alternative plans or options, a set of criteria by which the alternatives are to be judged, and a method for ranking the options based on how well they satisfy the criteria (RAC 1992). This process includes weighting and evaluating criteria, and methods to aggregate data when required (Froger and Munda 1998).

This paper evaluates the utility of using compensatory and non-compensatory multi-criteria analysis techniques to evaluate and compare various options for farm forestry development on the Darling Downs in southern Queensland, Australia. The use of multi-criteria analysis for evaluating farm forestry or other land-use practices in Australia has focused on evaluating alternatives from an economic, ecological, social and cultural perspective, and thus identifying trade-offs between these considerations. Further to these trade-offs, fatal flaws of each possible land-use need to be identified. This analysis incorporates community and other stakeholder opinion combined with expert opinion in a transparent approach consolidating the available data in a single framework.

The paper first briefly reviews compensatory and non-compensatory aggregation techniques used in multi-criteria analysis. The utility of applying two of these techniques in combination for land-use management is then examined. For the case study, the process of eliciting stakeholder driven options and expert evaluations of the relative performance of the options is described. The farm forestry options and evaluation criteria for the case-study area are then outlined. Finally, the outcomes and conclusion of the case study and an appraisal of the process and analysis are presented.

COMPENSATORY AND NON-COMPENSATORY MULTI-CRITERIA ANALYSES

In multi-criteria analysis, relative weights are placed on the decision criteria by which the options are evaluated. This recognises that some of the criteria are more important to the stakeholders than others, and should attract greater weights in the analysis. Second, the scores that the options receive against each criterion judging their performance against that criterion (which form the *effects table*) are aggregated, i.e. combined to create an overall score for each option. A wide variety of techniques are available, these can be split into compensatory and non-compensatory techniques. In compensatory techniques poor performance in a number of criteria can be compensated for by high performance in the other criteria and may not be reflected in the aggregated performance of an option. In non-compensatory techniques poor performance in a number of criteria cannot be

compensated for by high performance in the other criteria and will be reflected in the aggregated performance of an option.

The more commonly used techniques are now reviewed and their strengths and weaknesses discussed.

The Multi-Attribute Utility Theory (MAUT) of Weighting and Aggregating
MAUT provides the theoretical basis for multiple criteria methods. MAUT states that the overall utility of an option (an option's attractiveness to the decision-maker) can be derived from the sum of the measured values of its attributes. The attributes are transformed into single dimensionless utilities using utility probability functions. These probability functions are assessed for each attribute and are often complex. They are the basis for standardising functions used in many evaluation methods (Keeney and Raffia 1976).

The SMARTER Method of Weighting and Aggregation
The SMARTER technique (Edwards and Barron 1994) has three variations, namely SMART, SMARTS and SMARTER, referring to Simple Multi-attribute Rating Technique, Simple Multi-attribute Rating Technique using Swings, and Simple Multi-attribute Rating Technique Exploiting Ranks. Edward and Barron asserted that SMART contained an error in logic, which was subsequently corrected in SMARTS. These techniques use linear approximation to standardise the scores to single dimensionless cardinal utility functions and a weighted additive aggregation function.

The Analytical Hierarchy Process (AHP) for Weighting and Aggregation
The AHP (Saaty 1980) provides a hierarchic framework for the evaluation of decision problems using multiple criteria. The AHP uses the definitions of relative importance to evaluate the weights placed on individual decision criteria and the score received by each option for a given decision criterion. The criteria are evaluated using pairwise comparisons; each criterion is assessed individually against all the other criteria. These comparisons are made by the stakeholders (or decision-maker) and are in the form of a statement of the relative importance of the pair of criteria. A clear advantage of this method is the ease with which stakeholders can answer the pairwise question, but this assumes that decisions are made under complete knowledge about the issue (Janssen 1991). Inconsistency is a major issue with AHP, in which circular statements can arise, e.g. Criterion 1 is preferable to Criterion 2, Criterion 2 is preferable to Criterion 3, and Criterion 3 is preferable to Criterion 1. To counter this, an inconsistency ratio is calculated. Saaty (1994) asserted that an inconsistency of less than 0.1 (on a scale up to 5.84) represents a tolerable error in measurement and does not bias the result. With a small number of criteria it is possible to achieve consistency according to this measure, but as the number of criteria increases achieving consistency becomes increasingly difficult (Robins 1999). To address this problem Saaty (1980) suggested a maximum of between five and nine criteria.

Rank Order Methods of Weighting

Rank order weighting techniques are commonly used for assigning relative weights to a set of criteria. These weighting techniques assign weights to individual criteria according to a statement of importance or rank. These are usually in the form 'Criterion 1 is more important than Criterion 2, which is more important than Criterion 3, which is more important Criterion 4', and so on. Given these statements, a set of feasible weights can be defined, as well as the probability density function for all the feasible weights. The Rank Order Centroid (ROC) − as used in the SMARTER technique (Edwards and Barron 1994) − and the Expected Value Method (Nijkamp *et al*. 1990), use the centroid value as the weight for the criteria. The centroid value is also the most probable or expected value. Alternatively, the Range of Values method (Yakowitz *et al*. 1992) reports the extreme values of this probability density function, the maximum additive value and the minimum additive value.

The Weighed Summation Method of Aggregation

Weighted summation (Janssen 1991; Yakowitz *et al*. 1997) is the simplest and most commonly used aggregation technique. It is also described as the multi-attribute value (MAV) technique (Barron and Barrett 1996). The value accorded to an option is the sum of the value the option receives for each criterion multiplied by the weight given to that criterion. The weights for the criteria are assigned by the decision-maker or stakeholders to reflect the relative importance they place on the criteria. Weights may be directly assigned or assigned using a ranking process or pairwise comparisons that are usually embedded in the tool being used. The weighted summation technique is one of many methods included in Multi-Attribute Utility Theory (see Keeney and Raffia 1976), and whilst other techniques have a stronger theoretical basis they are rarely used because they are complicated and time consuming (Winterfeldt and Edwards 1986).

The Electré Method of Aggregation

The Electré (*El*imination *e*t *c*hoix *t*raduisant la *ré*alité or Elimination and choice corresponding to reality) method (Cook *et al*. 1988, Roy 1991, Janssen 1991, p. 61) uses pairwise comparison of options with regards to the measured value of each criterion. Each pairwise comparison assesses the criteria using a concordance and a discordance measure. The concordance index is derived from the differences between all criteria for the two options. The discordance index reflects the maximum difference between any individual criterion in the two options. Threshold values are set for concordance and discordance. For example, when comparing option 1 with option 2 for a given criterion, option 1 is said outperform option 2 if the following statement is true:

> The difference between the criterion value for option 1 compared to that for option 2 is greater than the concordance threshold and smaller than the discordance threshold.

The concordance index measures the relative overall performance of the options, while the discordance index measures poor performance in individual criteria. The rationale of the discordance index is that overall good performance in most criteria

cannot compensate for poor performance in an individual criterion. Five versions of the Electré method have been proposed (Roy 1991; Simpson 1996), these being Electré I, II, III, IV and TRI. Electré I can be used for selection problems, Electré TRI for assignment problems, and Electré II, III and IV for ranking problems. Electré II is used in this study. A detailed description of the Electré II method can be found in Jeffreys and Lawrence (in press).

The Regime Method of Aggregation

The Regime method (Hinloopen and Nijkamp 1990) uses pairwise comparison of options to determine dominance. Each option is compared on a criterion-by-criterion basis, for a given criterion against the same criterion in a second option. If a given option outperforms another option with respect to every criterion, the given option is said to strictly dominate the other option. However, usually the number of criteria against which performance is highest varies between options. Under the Regime method, the probability that an option is dominant is calculated (as the number of dominant criteria over the total number of criteria). The sum of these pairwise probabilities of dominance is the overall probability of dominance, and this is the measure by which the options are ranked.

The Evamix Method of Aggregation

Evamix (Voogd 1983) also determines dominance of an option on a criterion-by-criterion basis; it is especially designed for mixed (quantitative and qualitative) data. The quantitative and qualitative scores are standardised separately to a 0 to 1 range. The degree of pairwise dominance for each pair of criteria is calculated, as the difference in score received by the higher performing option compared to the poorer performing option. The value assigned to each option is the weighted sum of the dominance scores. The weights can be derived by any of the weighting techniques. The outcome of this aggregation is a similar to the outcome of the weighted sum; the relative performance of the options is the same but there is difference in the scale of the measure of performance.

In each of the Evamix, SMARTER, MAUT, AHP and the weighted summation techniques, the performances of the criteria are aggregated using a weighted sum. The Regime technique considers only the number dominant criteria disregarding the degree of dominance. In this respect all of these techniques are compensatory techniques, in that poor performance in any one criterion can be compensated by overall good performance in the other criteria and that one criterion can be traded off against another (Cook *et al*, 1988, p. 901). Evamix, SMARTER, MAUT, AHP, and the weighted summation techniques differ little in their outcomes, given the same effects table and weights are used. SMARTER, MAUT and AHP employ a weighted additive function to aggregate the scores received by each option. The techniques vary in the methods employed to transform measured data into the single dimensionless utilities used when aggregating the option's performance against the individual criteria. AHP uses expert opinion of the relative performance of the options against each criterion in turn to quantify the single dimensionless utilities. SMARTER employs linear approximations to standardise the measured data for each criteria and quantify the single dimensionless utilities and MAUT employs utility probability functions. Linear approximations are not valid in all cases and utility probability functions tend to be complex, difficult to evaluate and highly

specific to a given context. The weighted summation technique (Janssen 1991) uses linear and non-linear approximations as appropriate to quantify the single dimensionless utilities. This technique is simple and most likely to gain acceptance from the stakeholders.

Electré is the only widely used non-compensatory technique. Non-compensatory techniques offer benefits to decision-makers not provided by the compensatory techniques, these will be discussed in the next section. However, the algorithms are complex and this technique may have problems gaining acceptance from the stakeholders.

THE USE OF COMPENSATORY AND NON-COMPENSATORY TECHNIQUES IN COMBINATION

As a result of the above review of techniques, this study focuses on use of two aggregating techniques in combination with a single weighting technique. These are the weighted summation (Janssen 1991; Yakowitz *et al.* 1997) and Electré II aggregation techniques (Roy 1991), and the Rank Order Centroid (ROC) weighting technique (Edwards and Barron 1994). The ROC technique was chosen for this study because it is easy to elicit the rank orders from the stakeholders and this technique has a strong theoretical basis (Edwards and Barron 1994).

The weighted summation technique provides a sound measure of the overall performance, is logically simple and easily gains the acceptance of stakeholders. It is a compensatory aggregation method. Compensatory methods provide an overall measure of performance but tend towards the mean; that is, the result of using a weighted average tends to produce results that cluster around the mid-point of the score range. High performance in the majority of criteria will compensate for poor performance in one or more criteria. An option that has high performance in all criteria may have the same aggregate performance as an option that has exceptionally high performance in a large number of criteria and exceptionally poor in some criteria.

Electré II is a non-compensatory aggregation method which checks for poor performance in a number of criteria, by using the discordance test. Poor performance in one or more criteria amongst high performance in the other criteria will be reflected in poor aggregate performance. An option with sound to high performance in all criteria will outperform the option with exceptionally high performance against the majority of criteria and exceptionally poor performance against a few criteria. Electré II is a complicated method and is not easily communicated to, or understood by, persons without an advanced understanding of mathematics. Consequently, the method has not received wide application to natural resource management outside of theoretical studies.

When there is general agreement about ranking of options using the two aggregation techniques, no further investigation is required. If there is disagreement between the techniques and the performance of one or more options is relatively low using the Electré analysis compared to weighted summation, it can be concluded that these options have one or more poor performing criteria. These criteria can be identified by examining the effects table. The poor performance according to these criteria should then be judged as to importance in land-use decisions. If the criteria

have been identified as highly important to the stakeholders then the options should be considered as undesirable options. If the criteria have been identified as having low importance to the stakeholders the options may still be considered as desirable.

As regards computer software, the package Definite (Janssen 1991 and Janssen *et al.* 2001) is a high-end multi-criteria analysis tool, modular in structure and with high functionality. The problem definition module includes the ability to construct criteria hierarchies and the effects table, as well as evaluate the options by using various methods, and can undertake correlation analyses on the criteria. The multi-criteria analysis module includes many aggregation and weighting techniques. Definite was chosen for this application because it includes all the multi-criteria analysis discussed, including the Electré and weighted summation aggregation techniques and the Rank Order Centroid weighting technique. Definite also includes functionality for cost-benefit analyses and sensitivity analyses.

Mathematics of the ROC, Weighted Summation and Electré II Techniques

The Rank Order Centroid Weighting Technique
This weighting technique converts the rank order of criteria importance into a set of ordinal weights following a simple algorithm described by Edwards and Barron (1994). Given that criterion 1 in more important than criterion 2, and criterion 2 is more important than criterion 3 ($Cr_1 \geq Cr_2 \geq Cr_3$), the weight assigned to each criterion would follow a similar rule $w_1 \geq w_2 \geq w_3$, where w_j is the possible weight applied to criterion j.

If $Cr_1 \geq Cr_2 \geq \ldots \geq Cr_j$
then $w_1 \geq w_2 \geq \ldots \geq w_j$

If   k is the number of criteria

then $w_1 = (1+1/2+1/3+ \ldots +1/k)/k$
                       $w_2 = (0+1/2+1/3+ \ldots +1/k)/k$
                       $w_3 = (0+0+1/3+ \ldots +1/k)/k$
                       $\vdots$
                       $w_j = (0+ \ldots +0+1/k)/k$

More generally, the weight of criterion j is:

$$w_j = (1/k) \sum_{i=j}^{k} (1/i)$$ Equation 1

The Weighted Summation Aggregation Technique

The weighted summation aggregation technique takes the form (Janssen 1991, Barron and Barrett 1996):

$$V(w,v) = \Sigma_j \, w_j \, v_j \qquad\qquad \text{Equation 2}$$

where V = the weighted value or overall score for a given option

                      w_j = the weight for a given criterion j

                      v_j = the value or score for a given option with respect to criterion j

The Electré II Aggregation Technique

The first step in the Electré II technique, as described by Goicoechea *et al.* (1982), Roy (1991) and Simpson (1996), is to establish a complete rank order of the options using a number of tests. The first three of these are the indifference test, the preference test and the veto test. These are evaluated between two options for each of the criteria. These tests are now outlined.

1. The indifference test is designed for testing that Option A is indifferent to another Option B (notation *AIB*) for a given criterion. This allows for options with a small variation in score to be considered equal. In Electré II the decision-maker sets the indifference measure *q* for each criteria.

    $$\textbf{AIB} \;\; \text{if} \;\; |\, a_j - b_j \,| \le q_j \qquad\qquad \text{Equation 3}$$

    where a_j is the performance (the score it receives in the effects table) of option *A* on criterion j, b_j is the performance of Option B on criterion j, and q_j the indifference measure. The indifference measure will vary depending on the score range of the criteria.

2. The preference test evaluates whether an Option A is preferred to another Option B (notation *APB*), that is Option A outperforms or outranks Option B. This determines a strong or strict preference for Option A; that is, the score received by option A for criterion j is considerably better than that for option B. The preference threshold p_j is the level at which the decision-maker considers Option A to strongly outperform Option B.

    $$\textbf{APB} \;\; \text{if} \;\; a_j > b_j + p_j \qquad\qquad \text{Equation 4}$$

    where a_j is the performance of option *A* on criterion j, b_j is the performance of option B on criterion j, and p_j is the strong preference threshold. This test is applied to all the criteria and the results from all the criteria are considered further in the analysis.

3. The veto test evaluates whether an Option B is not preferred to another Option A; that is, the score received by option B for criterion j is considerably worse than that for option A (notation *BPA*). The Veto level v_j is the level at which Option B is not preferred to Option A, for any criterion. If the option B performs at a level that is lower than the performance of

option A by a greater than the veto level for any criterion, Option B is always not preferred to Option A, regardless of the scores in the other criteria.

$$\text{BPA} \quad \text{if} \quad a_j + v_j < b_j \qquad\qquad \text{Equation 5}$$

where a_j is the performance of option *A* on criterion j, b_j is the performance of option B on criterion j, and v_j is the veto measure. This test is applied to all the criteria. Failing this test in one criterion will result in Option B always being considered not preferred to Option A.

The performance of a set of two options for each criterion can be assigned. This can be categorised into four groups. The first is indifferent *I* group, the comparisons that fulfil equation 3, the second the strongly preferred *P* group, the comparisons that fulfil equation 4 or equation 5. The third group *Q* is a group of weak preference all those that fall between the indifferent set and the strong preference set. A fourth group *R* is created from the residual – those that failed all of the above tests – and these are deemed to be incomparable.

Using these threshold tests and the subsequent group Electré II technique builds an outranking relationship *S*, for each criterion. This group (notation aS_jb) is the set for each criterion where option A is at least as good as Option B.
Therefore for criterion j:

aS_jb:A is at least as good as B on criterion j if $a_j \leq b_j - q_j$

$$\{aS_jb\} = \{aP_jb\} \ \text{U} \ \{aQ_jb\} \ \text{U} \ \{aI_jb\} \qquad\qquad \text{Equation 6}$$

Using the groups *S, P,* and *Q,* Electré specifies values known as the concordance and discordance coefficients. The concordance coefficient is a measure of the strength of the argument *A is at least as good as B*, *c(A,B)*. The discordance coefficient is the strength of the counter argument; that is *A is not as good as B, d(A,B)*. In many examples the criteria do not carry equal weights. Weights are applied to each criterion using the ROC technique. These weights are included in defining the Concordance and Discordance indices.

$$c(A,B) = \Sigma \, P \,(w_j) \, / \, \Sigma \,(w_j)$$

Using the ROC weighting technique, *$\Sigma (w_j) = 1$*, so in this example

$$c(A,B) = \Sigma \, P \,(w_j) \qquad\qquad \text{Equation 7}$$

The next stage of the Electré II technique requires the decision-maker to set concordance and discordance thresholds. The level of the concordance threshold c^* and the discordance threshold d^* are set according to the aims of the analysis. High levels are likely to filter out all but the better performing options, while lower levels will identify acceptable and unacceptable groups of options. That is, when the concordance threshold c^* and the discordance threshold d^* are set to a high level,

relative to the range of scores received by the options, the most preferred options will have substantially higher performance in most criteria and no critically poor performing criteria.

The following decision rules are applied to the pairwise comparison of all the options against each other.

A outranks B if $\quad c(A,B) \geq c^*$ and $d(A,B) \leq d^*$

A outranks B if $\quad c(A,B) > c^*$ and
$\quad c(B,A) \geq c^*$ and
$\quad d(B,A) \leq d^*$

A and B are incomparable if

$c(A,B) \geq c^*$ and $d(A,B) > d^*$ or
$c(A,B) > c^*$ and $c(B,A) < c^*$ or
$c(A,B) \leq c^*$ and $c(B,A) < c^*$ and $d(B,A) < d^*$

$$\text{Equation 8}$$

Statements of outranking can be drawn from the outcomes of the decision rules. The statements of outranking can then be interpreted as an ordinal ranking of the options. Options that are incomparable or outrank the same group of options should be given equal ranking. These ranks can be displayed as lists of position or as bar charts.

CASE STUDY BACKGROUND, METHOD, OPTIONS AND CRITERIA

A multi-criteria analysis was conducted in which compensatory and non-compensatory multi-criteria analysis techniques were applied to compare potential forestry options for the Hodgson Creek catchment on the Darling Downs in southern Queensland. The eastern edge of the Hodgson creek catchment is formed by the western slopes of the Great Dividing Range, which descends steeply to the plains that cover the majority of the catchment. The high land areas lie on the south-west edge of the city of Toowoomba and are predominantly rural residential. The west of Hodgson Creek catchment contains fertile cropping land with some grazing country. The catchment contains little remnant vegetation, comprising mainly dry open sclerophyll woodland in the highland areas and native grasslands in the drainage gullies. The catchment is in the medium to low rainfall zone with average annual rainfall of approximately 700 mm.

The purpose of this study was to provide an assessment of the various options for land-use change which includes farm forestry as a new land-use in Hodgson creek. The assessment was required to identify the economic, environmental and social value of alternative farm forestry options. A set of decision criteria that reflected the objectives of economic enhancement, environmental enhancement and social and cultural enhancement, was developed with input from various stakeholders in Hodgson creek. Furthermore, the assessment sought to identify trade-offs between these objectives.

The Process of Developing a MCA for Farm Forestry in Hodgson Creek
The MCA for farm forestry in the Hodgson Creek catchment was developed through an extended process including consultation with stakeholders and technical experts. The stakeholders involved in this study included local landholders (all broadacre farmers), the local Landcare coordinator, forestry industry representatives, local government officers (Pittsworth Shire Council), and state government extension staff in the Department of Natural Resources and Mines (NR&M) and the Department of Primary Industries (DPI). The expert group included researchers, extension staff and managers from state government agencies (NR&M and DPI) and the University of Southern Queensland. Input from stakeholders was obtained in a one-day workshop at Felton, within the catchment, in March 2001. Input from experts was obtained in two one-day workshops in June 2001. The MCA development process proceeded through three phases, as summarised below:

Phase 1: Development of options, criteria and importance orders
1. An initial MCA workshop to identify a preliminary list of options and criteria was conducted involving only technical experts, without the assistance of spatial information. (The results from the initial MCA workshop were the starting point of the second analysis, involving both stakeholders and technical experts).
2. The first round results were presented to the stakeholder reference group, along with detailed descriptions of the options including maps of the possible spatial extent of the options.
3. Options and criteria were further discussed in the stakeholder workshop.
4. A final set of options was defined from the preferences of the stakeholder groups. Some options were removed or substantially changed to reflect the views of this group.
5. A similar process occurred with the criteria, which were evaluated with regards to their relevance and importance considering the values and goals of the stakeholder group. During this process, some criteria were added, removed or modified. Three stakeholder groups were present at this meeting, and each group produced separate importance orders. These groups were landholders, DPI and NR&M extension officers, and local government officers (of the Pittsworth Shire Council). This new set of options, criteria and importance orders formed the basis of the second round analysis.

Phase 2: Development of the effects table
1. Persons with local farm forestry knowledge were invited to form the Technical Reference Group (TRG) for the final analysis.
2. The options were scored against the criteria, during two focus group sessions. The options were assessed using the considered opinions of those experts present.

3. The options were considered at two time scales, initially defined as the short term and long term. The TRG further defined these periods.[1]

Phase 3: Analysis of effects table and ranking of options
1. The effects table was analysed using the MCA tool Definite. The analyses used three rankings representing the views of the three stakeholder groups. The criteria were also placed into a hierarchy and divided into economic, environmental and social criteria.
2. Two aggregation methods were used, these being the weighed summation (chosen for transparency and acceptability with stakeholder groups), and Electré II (to highlight any poor performance in individual criteria).[2]

The outcome of the process for developing the farm forestry MCA was a set of farm forestry options considered feasible by both stakeholder and expert groups. A set of evaluation criteria reflecting the goals and objectives of the stakeholders – including the relative importance of each criterion – was produced. Of the three groups present in the stakeholder meeting only the results of the analysis using the preferences of the landholders are presented in this paper. In this example, the outcomes of the three analyses produced similar results, although this may not be true in all situations. Where disagreement appears between stakeholder groups this disagreement would be highlighted and discussed by the analyst. It may be the case that an option including elements of the most preferred options of the different groups could be developed to satisfy all parties. Details of the analyses from all three perspectives are provided in Jeffreys (in press).

The Farm Forestry Options
In consultation with landholders, government officers, Landcare officers and technical experts in farm forestry, eight management practices were defined (Jeffreys and Cockfield, in press).

1. An approximation of current land use
This scenario is based on assumptions about 'typical' land uses, and provides a baseline against which the others are measured. For an alternative land use to be viable it must perform at least as well as the current land use.

2. High-priority salinity prevention
This option involves identifying saline and at-risk areas in the catchment, especially the discharge zones, and placing farm forestry on the associated recharge zones, higher in the catchment.

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[1] Final definitions were the *Transitional period*, that time during which the new forestry industry is being established in the catchment, also defined as the *Cost period*, of the first five to 10 years, and the *Steady-state period* or the *Equilibrium period*, the time when a forestry industry has been established in the catchment, at about year 30 to 40. However, only the results of the transitional time period are discussed in this paper.
[2] In this study the concordance threshold c^* was set at 60% of the range and the discordance threshold d^* at 47% of the range. These high values ensured that any potential fatal flaws were reflected in poor performance of an option.

3. Medium-priority salinity plantings
Similar to Option 2, but with a greater proportion of the recharge area planted.

4. Additional under-used areas
Similar to Options 2 and 3, but with trees planted on additional areas recognised as having limited value for conventional agricultural production, especially if adjacent to the priority salinity areas.

5. Commercial plantations (with corporate land ownership)
Medium-scale corporate investment in purchase of land and establishment of forestry in the higher rainfall areas of the catchment.

6. Commercial plantations (with leased land)
Similar to Option 5, except that land is leased by the corporation from landholders, potentially increasing the availability and decreasing the cost of land.

7. Private medium-sized plantations
Medium-scale forestry planting, undertaken by landholders.

8. Agroforestry (plantations and grazing)
Establishing of wide-spaced plantations, in conjunction with improved or native pasture or even fodder crop strips in more fertile areas.

The Criteria for Evaluating the Farm Forestry Options
The evaluation criteria have been defined considering the three major perspectives in land-use management, namely economic, environmental and social (including cultural) considerations. This approach is also useful in assessing the extent to which the forestry options achieve the goals of sustainable development, as defined by IDRC (1996).

Table 1 lists the performance criteria used to evaluate the forestry options considered in the Hodgson creek MCA. The 'rank' columns in Table 1 indicate the relative importance of the criteria for evaluating farm forestry options. This relative importance was defined by landholders (broadacre farmers) in the lower section of the Hodgson Creek catchment. In this list, 1 denotes a criterion of high importance, through to 5 for least importance.

Table 1. Rankings of the performance criteria for evaluating farm forestry

Economic criteria	Rank	Environmental criteria	Rank	Social criteria	Rank
Forestry revenue – growth	5	Shelter effects	2	Aesthetic amenity	1
Forestry revenue – royalty	5	Soil resource quality	1	Change management requirements, including reskilling	4
Infrastructure costs (community)	4	Carbon sequestration	4		
		Water quality	1		
Regional impact	4	Salinity control	1	Consistency with local, state and federal government regulation and policy	2
Regional output	4	Biodiversity (local native)	2		
Profit – farm	1				
Profit – regional	1	Water quantity	2		
Property value	3	Cumulative impacts	2	Net employment	3
Rating treatment	4	Displacement of existing native bio-systems	3	Maintaining services	3
Risk profile	2			Community capacity	3
Risk of policy change	4			Community cohesion	2
Equity of financial returns	4	Habitat quality	3	Community acceptance	2
Cash flow – upfront costs	2	Pest habitat	1	Population turnover	2
Cash flow – debt servicing	2	Air quality (spraying of agricultural chemicals)	1	Equity	2
Critical mass	4			Community health	2
Flexibility of land-use	3			Health effects on farm families	1
Liquidity of assets	3				

MCA EVALUATION OF FORESTRY OPTIONS FOR THE CASE-STUDY AREA

Figure 2 presents in graphical form the aggregated performance of the farm forestry options. The panel on the left summarises performance according to the weighted summation aggregation technique, and that on the right according to Electré II. The upper bar charts presents the aggregate result of the environmental, economic and social criteria, while the lower sets of bar charts depict findings for the economic, environmental and social criteria individually.
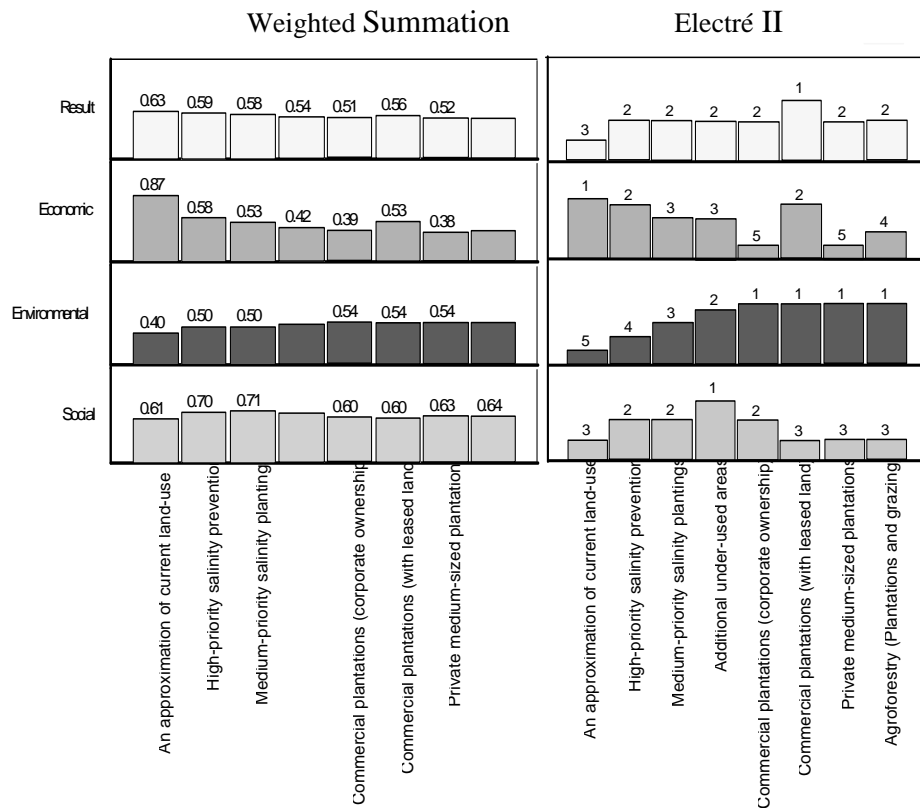
Figure 2. Outcomes of the MCA in Hodgson Creek

In Figure 2, the left hand panel should be considered first. The height of each bar represents the performance of an option – the higher the bars the better the performance. The number that appears on top of each bar is the aggregate score for that option, i.e. the weighted sum of the individual scores against all the criteria. Considering the four bar charts in this panel, an option will only be considered to have high overall performance if it achieves average or high scores and no low scores in each bar chart, i.e. no poor performance in any of the perspectives (economic, environmental or social). The panel on the right of Figure 1 presents the aggregated score using the Electré II aggregation and should be considered second. These bar charts display the ordinal ranking of the options; the numbers that appear in these bar charts reflect these rankings. The highest performing option is ranked 1, second highest 2, and so on

The weighted summation is used to assess the overall performance of the options and Electré II is used to test for the presence of fatal flaws. If the rank achieved by a particular option under Electré II does not reflect the rank it receives using the weighted summation, it is likely that there are one or more poor performing criteria. These criteria should be identified from the effects table. The analyst should then consider whether the poor performance in these criteria represents a fatal flaw in this option or if they are compensated for by high performance in the other criteria.

Comparison of Relative Performance of the Options According to Economic, Environmental and Social Criteria, Individually and in Combination

Using *economic criteria* alone 'Current practice' is the best option, with high overall performance and no critically poor performance. Other options that perform well considering only economic considerations are the 'High-priority salinity plantings' and 'Commercial plantations (leased land)'. The salinity plantings are small in area and in generally under-productive areas so do not displace other land uses, while 'Commercial plantations (leased land)' pay annuities, thus increasing the performance in the *profit* and *cash flow* criteria.

Using *environmental criteria* alone, the forestry options outperform 'Current practice'. The large-area forestry options, including the 'Agroforestry' option, perform better than the small-area forestry options.

Using *social criteria* alone the 'High-priority salinity plantings', the 'Medium-priority salinity plantings' and 'Additional under-used areas' perform well in both the weighted summation and Electré II analyses, with 'Additional under-used areas' performing the highest.

Using *all three major perspectives* (economic, environmental and social) aggregated, under Weighted Summation 'Current practice' performs best, and 'High-priority salinity plantings' and 'Medium-priority salinity plantings' perform well, followed by 'Commercial plantations (leased land)' and then the other options. There is a general trend that performance drops as the area trees planted increases.

Using *all three major perspectives*, under the Electré II analysis, the results are quite different. The 'Commercial plantations (leased land)' option is ranked first, all the other forestry options second and 'Current practice' last. 'Commercial plantations (leased land)' perform well overall as the scores for the individual criteria are generally high and it has few exceptionally poor performing criteria. This option scores poorly in the economic criterion of *liquidity of assets* (as do all the forest options) but no others. The drop in performance of 'Current practice' is due to critically poor performance in a number of environmental and social criteria.

Overall Conclusions for the Multi-Criteria Analysis

All the forestry options outperform 'Current practice' from the environmental and social perspectives, but from an economic perspective 'Current practice' outperforms all of the forestry options. For forestry to be a viable option in this catchment, measures need to be taken to ameliorate this poor economic performance. The drop in performance is due to critically poor performance in the criteria *habitat quality, shelter effects, soil resource quality, carbon sequestration, net employment, maintaining services* and *community capacity*. These poor performing criteria, if present in an area of high concern, may prove to be fatal flaws in the management practice. Thus the technique of using compensatory and non-compensatory techniques – the weighted summation and Electré techniques – has shown high utility in assessing natural resource, environmental and land-use management practices in terms of overall performance and fatal flaws.

The option 'Commercial plantations (with leased land)' is most promising in this catchment followed by the option 'Additional under-used areas'. The 'Agroforestry' option also merits further investigation. 'Commercial plantations (with leased land)' is considered the most promising option largely because it is the best performing forestry option from the economic perspective. This is largely due to the payment of annuities to the landholder by the organisation leasing their land. This option has high overall economic and environmental performance. *Air quality* was a major environmental consideration for landholders present at the stakeholder meeting. Large-scale forestry requires aerial spraying of agricultural chemicals, and alternative methods of applying these chemicals would need to be considered for this option to be acceptable in the Hodgson creek catchment. 'Commercial plantations (with leased land)' has average performance in the social perspective under the weighted summation analysis and poor performance in the Electré II analysis. This is largely due to a drop in performance in the criteria *net employment* and *maintaining services*. However, all the options perform poorly against this criterion, suggesting that the root of these problems lies elsewhere and will not be solved in the long term by introducing a forestry industry in the catchment. This option does however outperform 'Current practice' in both of these criteria.

The option of forestry in 'Additional under-used areas' is worthy of further consideration, especially if the areas are also those identified where forests assist in salinity prevention. This option has high performance from the environmental and social perspectives. Environmentally, it does not perform as well as the larger area forestry options. The effect on the regional economy would be small because the planted area is small, and the option has low scores in *critical mass* and farm and *regional profitability*. This poor performance could be ameliorated by large-scale forestry being established in neighbouring areas. This small-scale forest industry could utilise the resources of a nearby large-scale plantation forestry industry, and therefore is worth considering in combination with the previous option.

Whilst the 'Agroforestry' option has major weaknesses in key economic criteria, it has high performance from both the environmental and social perspectives. Also, there is anecdotal evidence that agroforestry will increase grazing productivity. Low scores in the important economic criterion of *farm profit* may however be insurmountable.

DISCUSSION

Multi-Criteria Analysis has proved useful for the integrated and holistic evaluation of projects and management options in natural resource and environmental management. This study demonstrates the utility of MCA for assessing farm forestry options on the Darling Downs from an economic, environmental and social perspective as well as from an overall perspective. Previous MCA studies have tended to lose detail of the performance of practices in particular areas of concern; overall good performance is assumed to compensate for poor performance in specific areas and the presence of fatal flaws has been overlooked. This does not reflect the concerns of the wider community and may result in poor decisions. The use of compensatory as well as non-compensatory multi-criteria analyses addresses this problem. The compensatory technique has provided with a sound measure of

overall performance of a management practice, whereas the non-compensatory technique alerts the decision-makers to presence of poor performing criteria.

ACKNOWLEDGMENTS

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